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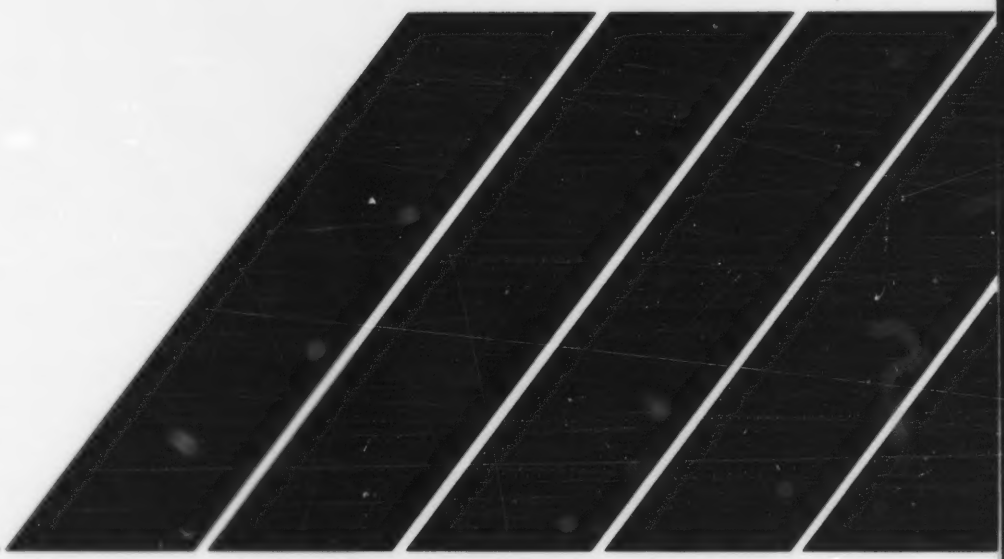
DESIGN AND PERFORMANCE OF RALOS 1,
A SOLAR-POWERED VEHICLE



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DESIGN AND PERFORMANCE OF RALOS 1, A SOLAR-POWERED VEHICLE

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
May, 1991

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Executive Summary

This paper describes the technical aspects of the mechanical, electrical, and energy storage designs of the solar racing vehicle RALOS1. The vehicle included a novel zinc/bromine flow battery energy storage system, that was developed in a collaborative effort between Team RALOS, the Electrochemical Science and Technology Centre (University of Ottawa), and Johnson Controls, Inc., Milwaukee, Wi.

A summary of the vehicle's performance during GM Sunrayce USA, July, 1990, is also included.

Résumé

En décembre 1988, la compagnie General Motors a lançait un défi aux institutions d'éducation poste-secondaire nord-américaines, celui de construire et de soumettre à une course transcontinentale un véhicule propulsé à l'énergie solaire. Surnommé GM SUNRAYCE USA, cette course de neuf jours et demi débutera à Walt Disney World, à Orlando en Floride pour finir au centre technique de General Motors à Warren, Michigan; un trajet de 3200 km de route empruntant l'Alabama, le Tennessee, le Kentucky et l'Indiana.

Le départment d'énergie des États-Unis et la societé du génie automobile se sont joints à General Motors et à la division moteur de Chevrolet pour la planification de cette incroyable course. Trente-deux équipes furent choisies parmi les soumissionnaires et chacune s'est vu attribuée la somme de 8 400$ CDN par les organisateurs.

En janvier 1989, un groupe d'étudiants en génie et sciences de l'Université d'Ottawa a décidé de se réunir avec comme objectif la construction d'un véhicule nouvelle technologie pour participer à la compétition de GM.

Un proposition de projet fut préparée, décrivant en détail les démarches envisagées par le groupe pour atteindre cet objectif. Entre autres il y avait : objectifs et motivations, administration du projet, calendrier des tâches, campagne de financement, ressources disponibles, conception préliminaire, information technique de base, test du véhicule, et stratégie de course.

En avril 1989, l'équipe reçevait une réponse d'acception de la proposition soumise. L'équipe se retrouvait donc parmi trente-deux équipes choisies d'un total de soixante et une, dont seulement une autre université canadienne, l'Université de Waterloo.

L'équipe a choisi comme nom RALOS. Ce mot, écrit à l'envers, donne <<solar>>, soit solaire en anglais; aussi, RA est le dieu égyptien du soleil. La dépendance et le lien avec le soleil sont donc mis en évidence, ainsi que entre l'équipe et le soleil: tous deux une source illimitée d'énergie, d'enthousiasme et de créativité.

Pour la course, la seule source d'énergie acceptée est le soleil. Des piles peuvent être utilisées pour emmagasiner l'énergie photovoltaïque. Pendant deux heures avant le début de la course (07H00 - 09H00) et deux heures après la fin de la course (18H30 - 20H30), chaque jour, les participants pourront charger les piles à l'aide du système solaire du véhicule. Les panneaux solaires doivent être contenus dans un volume de 4m de longueur, 2m de largeur, 1.6m de hauteur, et le véhicule dans un volume de 6mx2mx1.6m avec une hauteur minimale de 1m. Le véhicule doit être conforme à tous les codes de route.

Des étudiants de premier et de deuxième cycle de différentes disciplines se sont impliqués avec des professeurs et employés de la Faculté de génie de l'Université d'Ottawa ainsi que du Centre Scientifique et Technologique en Électrochimie (ESTCO). Dr. Bill Adams d'ESTCO et Dr. Atef Fahim du département de génie mécanique sont conseillers du projet. Les coordonnateurs étudiants sont Pierre Dugas, Serge Mokri et Wendy Pell.

L'équipe Ralos s'est classé 29e en finale de la course.

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RALOS1 - a solar/electric vehicle

Team RALOS, the University of Ottawa solar/electric vehicle racing team, competed in GM Sunrayce USA, during July of 1990. The development of a novel zinc/bromine flow battery energy storage system was a collaborative effort between Team RALOS, the Electrochemical Science and Technology Centre (University of Ottawa, Ottawa, Canada), and Johnson Controls, Inc., Milwaukee, Wi., USA.

GM Sunrayce was a staged 3,000km solar car race from The Epcot Center, Flo., to the GM Technical Centre, in Warren, Michigan, over an eleven day period beginning July 9, 1990. Vehicle trials and qualifications were conducted prior to the start of the race. The route followed secondary state and county roads in normal traffic, with road conditions ranging from very hilly, in the south, to relatively flat, in the north. Weather conditions varied from overcast and rainy to clear and bright. Thirty - two cars were selected in 1989 to participate in this event from Canada (2 teams), USA (29 teams), and Puerto Rico (1 team).

The rules of GM Sunrayce limited the capacity of the battery to 5kWh, and the dimensions of the photovoltaic array to remain within a 4 x 2 x 1.6 m box. The maximum vehicle dimensions could not exceed 6 x 2 x 1.6 m. The drivers were ballasted to 79kg. The only permitted source of energy was direct incident sunlight with exposure restrictions. The vehicles could charge from the solar panel from 0700 to 0900 hours, while racing, and from 1830 to 2030

hours daily, at all other items the PV arrays were disconnected from the battery.

Vehicle Design

Mechanical

The first step in the design process was to determine a solar array configuration. After examining the design of the vehicles which participated in the Australian First World Solar Challenge in 1987, the mechanical engineering group proposed a flat solar array, which would be supported on top of a streamlined vehicle. Three factors were considered:

i) a flat solar array was easier to fabricate, ie. panel, solar cell lamination, module attachment to panel;

ii) having the array separate form the body permitted work to be done in parallel;

iii) reliability of electronics for flat array would be increased as fewer power trackers were needed.

The vehicle's aerodynamic drag was also of concern, but at speeds lower than 80km/h, rolling resistance was more important. For this reason, and also because of limited personnel resources needed to conduct a comparative aerodynamic study, the increased drag created by having a flat panel on top of a streamlined body was deemed acceptable.

Vehicle lay-out was affected by several important factors:

i) weight distribution was critical for determining location of wheels, solar array, driver, and accessories. Proper weight distribution was important for vehicle handling and good road adherence of the propulsion wheel;

ii) the stability of the vehicle was also important for safety reasons. Full-scale wind tunnel testing (9 meter

National Research Council of Canada wind tunnel in Ottawa) was performed to determine the effects of the flat solar panel on stability and drag.

iii) aesthetics were also an important factor. In short, the car had to be both competitive and attractive.

The above considerations led to the lay-out shown in Figure 1. The vehicle has three wheels, the two in front are used for steering, and the back wheel is the propulsion wheel. The driver sits in front of the front wheels and is protected by a full Lexan (Reg. TM G.E.) canopy. The solar panel provides shade for the driver and can be tilted to maximize energy collection, and improve stability to crosswinds. The battery is located in the fuselage behind the front wheels.

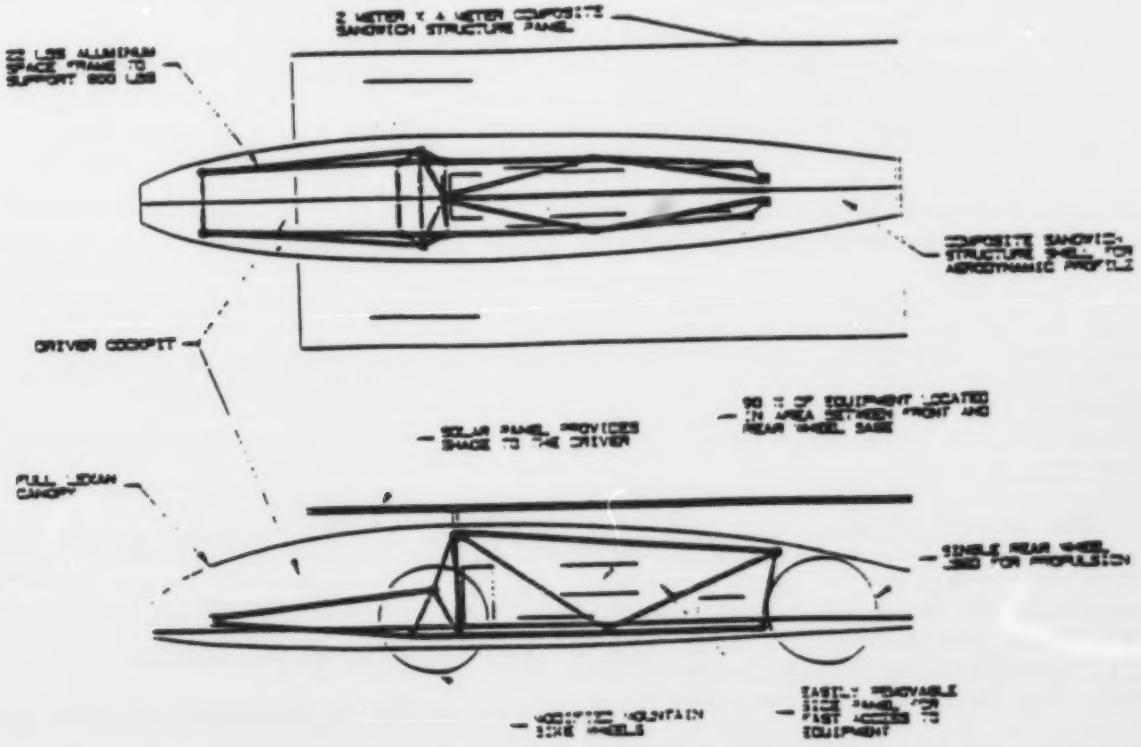

Figure 1: Schematic of RALOS1 vehicle

The components of this design included:

i) a 10 kg aluminum space frame, supporting the full weight of the vehicle, 360kg;

ii) an aerodynamically shaped body made of sandwich structure composite materials (glass-Nomex (Reg. TM DuPont) honeycomb-glass) and having a total weight of less than 22.5 kg;

iii) a 2m by 4m flat panel of sandwich structure composite materials to support PV modules;

iv) a worm gear and cables to orient the solar panel 20° from the horizontal in each direction, while driving;

v) hydraulic motorcycle disk brakes mounted on the front wheels providing braking;

vi) a lightweight steering system, the steering wheel is linked to a rack and pinion mechanism behind the driver using antagonistic cables, the steering wheel was telescopic and tiltable;

vii) easily removable side panels to permit fast access to the electronics, battery and drive systems;

viii) movable dashboard to let the driver in and out easily;

ix) a 6-point seat belt attached to the space frame and used to restrain the driver in case of accident.

"Keep it simple" was the design philosophy used. Team RALOS fabricated everything themselves in less than one year from concept to design and testing.

Drive Train

The electric motor is the key component of the drive - train system of an electric vehicle (EV). RALOS1 required a lightweight motor that could operate over the necessary ranges of torque and speed. The mechanical power and torque requirements measured at the wheel were predicted as functions of vehicle speed and road grade. The motor had to provide sufficient torque to accelerate from a

stop on a 10% grade hill, and sufficient torque and speed to allow the vehicle to cruse comfortably at 40 - 60 km/h.

The limited time for vehicle design and construction, as well as the limited resources at the university, prompted a decision to acquire a motor commercially. A 10 HP (at 10,000 rpm or 7.5 kW) Unique Mobility, Inc., motor was selected because the available energy from the sun and the batteries limited average consumption to about 900 W, and best efficiency was obtained if the motor was operated close to its rating. This motor, which weighs approximately 4 kg, is a brushless DC permanent magnet motor with a dedicated controller, weighing approximately 10 kg. The motor can be switched electrically between parallel and series windings to produce alternatively high speed and low torque, or low speed and high torque. The controller has built-in feedback to provide precise speed control, regenerative braking capabilities, and automatic current limiting in the event of the motor or controller over-heating.

The drive wheel was a 20 inch wheel, which was geared to the motor using a chain drive at a fixed ration of 11.28:1. A suitable cruising speed of 40 km/h, and a maximum speed of 80km/h were attainable on relatively flat terrain.

One design aspect of the UNIQ motor which posed some concerns and actually developed into a problem was the need to provide forced-air cooling to keep the stator windings from over-heating and subsequently burning.

Solar Energy Collection

It was estimated that the 8 m^2 array of 684 Siemens single crystal silicon solar cells (approximately 10 x 10 cm) with typical efficiencies of 12 to 13 % would yield approximately 1000 watts at peak power. The flat panel configuration provided uniform lighting conditions over the panel, and allowed three parallel strings of 228 cells in series to operate at identical voltages, possibly without the need for power conversion devices. PV cells are non-linear devices which produce maximum power at a voltage determined by the cell temperature and the light intensity. The cell configuration used here could be connected directly across the battery and motor since the nominal voltage of the battery coincided very closely to the value at which the solar panel operated during the majority of the day. The interrelation between the drive train and the solar array can be seen in Figure 2.

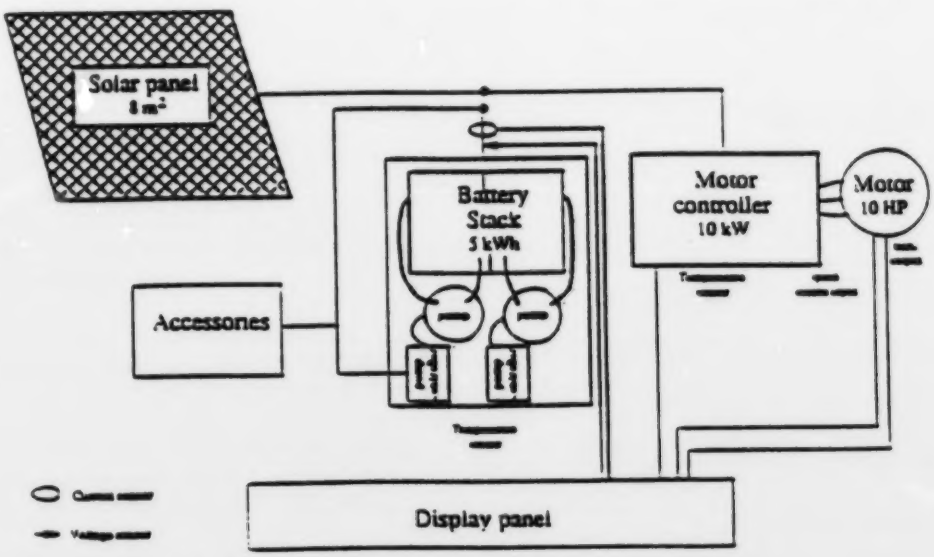

Figure 2: Energy Management Diagram

The Battery System

The energy storage system chosen for RALOS1 was an experimental zinc/bromine flow battery (1,2,3). The choice of the experimental system was unique to Team RALOS. The zinc/bromine battery is a young technology, that had its beginnings in the 1960's in the labs of Exxon Research. It has demonstrated (lab scale) good cycle life, ambient temperature performance, inexpensive components and an ability to be totally discharged every cycle without damage to the stack. These features make it ideal for EV applications. Most competitors used silver/zinc batteries, which, although having higher specific energy than zinc/bromine, have a limited cycle life. Thus, although possibly suitable for an 11 day race, the Ag/Zn batteries are not suitable for a commercial EV. Furthermore, the cost of the Ag/Zn system is very high due to the high cost of materials. Thus, the zinc/bromine system was chosen for its potential as an alternative to lead - acid for EVs and is believed to be a realistic system acceptable for commercialization in the future. An energy density of approximately 80 Wh/kg, suitable for use in a solar vehicle, was suggested in the literature.

The cell stack was designed and built by Johnson Controls, Inc. (4,5) for Team RALOS, the thermal management and circulation systems were designed and tested at the University of Ottawa. In the Zn/Br_2 flow battery, the anolyte and catholyte, containing the active material, are stored separately form the stack. These fluids are pumped through the stack when the battery is operating. The

need for pumps, valves, and tubing to connect the reservoirs to the electrodes assembly (stack), makes this battery quite complex and, therefore, much thought was required to integrate it into the vehicle. However, the flowing electrolyte provides excellent opportunity for thermal management not available in most batteries.

The battery stack consisted of bipolar electrodes connected electrically in series, with electrolyte flow through the cells in parallel. The system consisted of 45 cells (with an average cell voltage of 1.6V/cell); the nominal system voltage was 72V, and the energy density of the system was 78Wh/kg. The battery is shown schematically in Figure 3. More detailed description of this system is presented elsewhere(6).

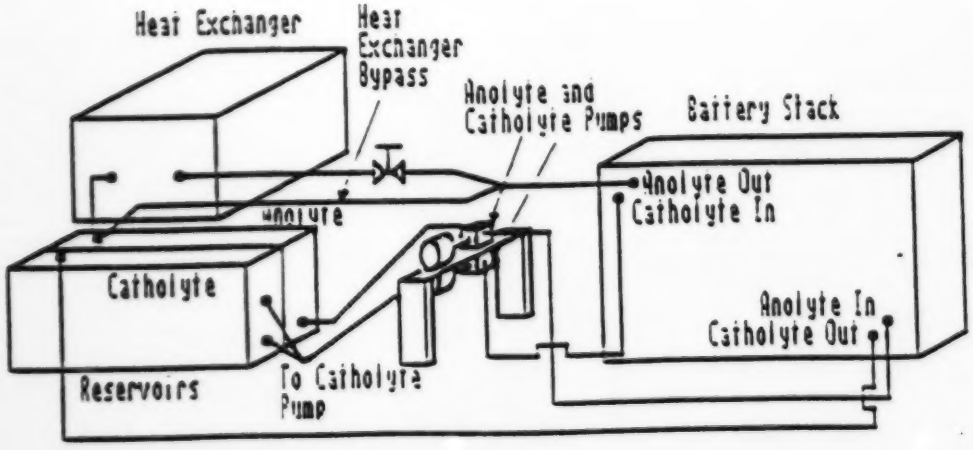

Figure 3: Schematic representation of Zn/Br_2 Battery

Performance

During the course of Sunrayce, RALOS1 required several modifications. The maximum power point trackers, which would enable the PV array to provide up to 1000 watts, did not perform as expected, and the panel output was reduced to approximately 650 W. On flatter terrain, the vehicle was able to travel at approximately 30 km/h on solar power alone. Figure 4 shows power consumed as a function of speed on level terrain.

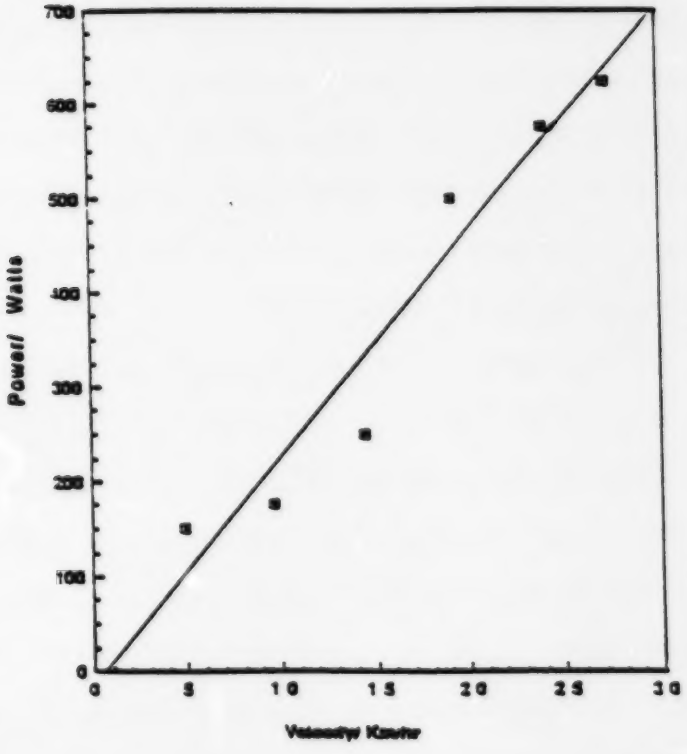

Figure 4: Power vs velocity for RALOS1 vehicle (including power requirements for pumps)

GM Sunrayce USA - a Summary

Team RALOS left Ottawa, for Florida at 4 pm on July 3, 1990. The convoy arrived at Disney World in Florida at 3 am on July 5, 1990. The car was assembled on July 5 to be ready for technical inspection and qualifying at Daytona, the following day. Unfortunately, the UNIQ mobility motor was damaged, during the drive to Florida, and required replacement. RALOS1 passed the technical inspections on July 6, including battery scrutineering, mechanical inspection, stability test and driver ejection test (6s). The UNIQ motor was not replaced until late in the afternoon, so the car did not pass the braking and manoeuvring tests the first day.

July 7: Second day of Qualifying. RALOS1 drove approximately 10km to the Epcot centre qualifying grounds. During the manoeuvrability test, the UNIQ motor shut-off, as the blower providing cooling to the motor failed. Qualifying was postponed until July 8.

July 8: Third day of Qualifying. RALOS1 again drove to the site of the qualifications. A wheel failure occurred during this trial. The day was spent fixing the wheel, after which RALOS1 qualified in 27th position.

Due to the experimental nature of the zinc/bromine battery, and to the problems associated with self-discharge, the battery was in an uncharged state at this time. GM officials had earlier indicated that there would be sufficient opportunity to charge

after qualifying on Sunday, at the last minute, the officials changed there mind, leaving only a short period to charge the battery. (A full charge would require 20A for 4 h). As a result, RALOS1 began GM Sunrayce with an uncharged battery.

July 9: Epcot Center, FL. to Floral City, FL. After taking part in the staged start, RALOS1 left the course to charge the Zn/Br_2 battery. This resulted in a battery penalty equivalent to approximately 1 days time. (30th place finish for the day)

July 10: Floral City, FL. to Tallahassee, FL. RALOS1 hit a deep pot-hole approximately 1 km into the second days race route. The king pin on the right A-arm to the wheel was severely damaged, and required replacement. A new part needed to be machined, and as Team RALOS was not carrying the required equipment, a local tool and die shop was contacted. Gene Dorr, Tool and Die, Floral City, Florida, provided the work and materials at no cost to Team RALOS. The afternoon of July 10 was spent charging, and waiting for the replacement part. (31st place finish for the day)

July 11: Tallahassee, FL. to Montgomery, AL. Repairs to the A-arm were completed, and the new part installed on the car. Modifications to the electronics were begun. RALOS1 entered the course at 4pm, but did not have sufficient power to climb a steep hill, and after approximately 3 mi, the vehicle stopped for charging. (30th place finish for the day)

July 12: Montgomery, AL. to Haleyville, AL. Modifications were made to the electronics, and the drive was begun at 12:15pm. A total distance of 29 mi was covered before the vehicle again

stopped at the base of a large hill. (26th position finish for the day)

July 13: Haleyville, AL. to Spring Hill, TN. RALOS1 travelled 15.2 mi and finished in 21st position for the day. The day was ended prematurely due to a motor failure.

July 14: Spring Hill, TN. to Bowling Green, KY. The motor was replaced and the vehicle resumed racing at 1:45 pm. A total distance of 56 mi was covered and the vehicle finished in 24th position.

July 15: Bowling Green, KY. to Louisville, KY. After 1 extra hour of charging, RALOS1 entered the course at 10:30. During the day a second charge period (approximately one and three quarters hours) was required. The battery had been run down to a low state of charge due to inefficient electronics, and bad weather. At 5:30pm, the Team RALOS chase vehicle was rear-ended. The days racing was ended prematurely. Fortunately no one was hurt, and there was minimal damage to the support vehicle. GM officials did not credit the team for the hour of lost driving, although a request was made. The vehicle covered approximately 80 mi, and finished in 27th position.

July 16: Louisville, KY. to Indianapolis, IN. RALOS1 began racing at 11 am, travelled approximately 80 mi, and finished in 25th position for the day. The racing day ended at 5:30 pm after a long downhill, where it was required that the vehicle stop to allow the motor to cool, after a long period of regenerative braking.

July 17: Indianapolis, IN. to Greenville, OH. RALOS1 began at

9:30am, taking part in the staged start at the Indianapoulos Speedway. During the course of the 120 mile race, Team RALOS replaced three flat tires (on front wheels). The vehicle completed the days course in 25th position.

July 18: Greenville, OH. to Mason, MI. After the long day on July 17th, the battery was at a low state of charge. The morning was spent charging the battery. A total of 60 mi were driven, and RALOS1 finished 30th overall.

July 19: Mason, MI. to Warren, MI. RALOS1 started in 30th position and had a successful final day. The car was working very well, with speeds of 25 mi/h on solar power alone. By the first checkpoint, RALOS1 had moved from 30th position, to 19th. The 85 mi race day ended with RALOS1 finishing in 14th position for the day.

RALOS1 finished in 29th position overall. Although, a top place finish was not achieved, the Team believed the event to have been a success.

Team RALOS was awarded a teamwork award on July 17. 1990.

Status, May 1991

RALOS1 is currently on display at The Baedal Cultural Centre, in Seoul, Korea. A team of 6 RALOS members recently visited Korea to display the solar vehicle. RALOS1 returns to Ottawa in September, 1991.

References

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3. G. Tomazic, S.E.A., "Advances in Zn/Br_2 Batteries for EVs and Energy Storage at S.E.A.", Paper presented at Annual Battery Conference, California State University, Long Beach, CA, Jan 16-18 (1990)

4. J.J. Bolstad, R.A. Vidas, J.P. Zagrodnik, "Zn/Br_2 Computer Model for Battery Applications Design", Paper EVS88-079, Proceedings of the 9th Intl. EV Symposium, Toronto, Canada (1988)

5. J. Zagrodnik, J. Bostad, R. Miles, " The Zn/Br_2 Battery: Recent Advances for EV Applications", Future Transportation Technology Conference and Exposition, Vancouver, Canada (1989)

6. W.A. Adams, E. Bernard, A. Fahim, A. Hicks, D. Ladd, S. Lines, L. Nash, J.C.T. Oliveira, W. Pell, G. Song, P.A. Eidler, "Design and Performance of Photovoltaic Zn/Br_2 Battery Propulsion System for a Solar Powered Electric Racing Vehicle", EVS90, Paper at Proceedings of the 10th Intl. EV Symposium, Hong Kong (1990)

Academic Work Associated with this Project

Theses:

BASc. Chem. Eng.
Stephanie Lines
"The circulation system of a zinc/bromine battery."

BASc. Chem. Eng.
Lisa Nash
"Thermal management in the zinc/bromine battery."

BASc. Mech. Eng.
Sean Rafferty
"Aerodynamics of RALOS1"

Papers Presented:

"Zinc/Bromine Flow Batteries. An example in a Solar/Electric Car", W.A. Adams, W. Pell, G. Song, University of Ottawa; Presented at ECS Fall Meeting, Ottawa, October 1990

"Design and Performance of a Photovoltaic Zinc/Bromine Battery Propulsion System for a Solar Powered Electric Racing Vehicle", W.A. Adams, E. Bernard, A. Fahim, A.R. Hicks, D. Ladd, S. Lines, L. Nash, J.C.T. Oliveira, W. Pell, G. Song, University of Ottawa; P.A. Eidler, Johnson Controls, Inc., Presented EVS10, Hong Kong, Dec. 1990.

"Design and Performance of Photovoltaic Zinc/Bromine Battery Systems for Transportation and Stationary Applications", W.A. Adams, E. Bernard, V.S. Donepudi, A. Fahim, D. Ladd, J.C.T. Oliveira, W. Pell, G. Song, University of Ottawa; P.A. Eidler, Johnson Controls, Inc., Presented Solarmobile im Alltag, Basel, Switzerland, March 17, 1991.

"Storage Battery and Fuel Cell Options for Use in Photovoltaic Systems", W.A. Adams, V.S. Donepudi, J.C.T. Oliveira, W. Pell, G. Song, University of Ottawa, Presented at SESCI Conference, Toronto, Ontario, June 24-26, 1991.

Budget

Revenue 88,185.61

Expenses:

Salaries:

1st yr Elec. Eng. Student, summer 1989
3rd yr Mech. Eng. Student, summer 1989

========== 10,450.02

Equipment and Supplies:

silicon solar cells
battery rental
lead acid battery backup
lumber
tools
battery test station
electronics

========== 53,836.49

Travel:

two trips to Johnson Controls, Inc., Milwaukee (4 people)
16 member team on Florida race
truck rental
gas
repair costs during race

========== 26,323.42

Other:

phone bills
shipping
customs
etc.

========== 2,752.56

RALOS Team List

Raed Abdullah
Bashar Abdullay
Etienne Bernard
Michel Boisvert
Paul Currie
Yves Dontigny
Pierre Dugas
Andrew Hicks
J. Tim Korstarye
Darcy Ladd
Peter Lauter
Jules Leduc
Stephanie Lines
Daniel Monette
Lisa Nash
Arghavan Nawaby
Dr. Julio Oliveira
Vivek Pathak
Wendy Pell
Stephane Quevillon
Patrice Quevillon
Sean Rafferty
Anne Marie Sibbald
Paul Therrien
Bohdan Tomiuk

Dr. Bill Adams
Dr. Atef Fahim

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Society of Automotive Engineers (Ottawa)
Springborn Materials
Sypher-Mueller International
TES Power Systems
Toshiba Canada
United States Department of Energy
University of Ottawa - Alumni Association
University of Ottawa - Faculty of Engineering
University of Ottawa - Inovation Fund
University of Ottawa - Students Federation
Vulcanium Corportation

Media Coverage

Local media coverage of the RALOS project was quite extensive. The following is a list of media coverage.

Le Doit, 18/7/90 p13
19/7/90
24/7/90
21/11/90

The Citizen 8/6/90
10/7/90
13/7/90
18/7/90
19/7/90
24/7/90
21/11/90

Montreal Gazette 21/7/90

The Ottawa Sun 14/6/90
11/7/90
16/7/90
20/7/90
24/7/90
25/7/90

Battery Man Magazine September 1990

CJOH TV 7/6/90
23/7/90

CBOFT TV 7/6/90
23/7/90

CBOT TV 7/6/90
23/7/90

CBC Windsor TV 23/7/90

CFGS 13/6/90

The Daily Sports, Seoul, Korea 17/4/91

The Kyung-Hyang Daily Newpaper 17/4/91

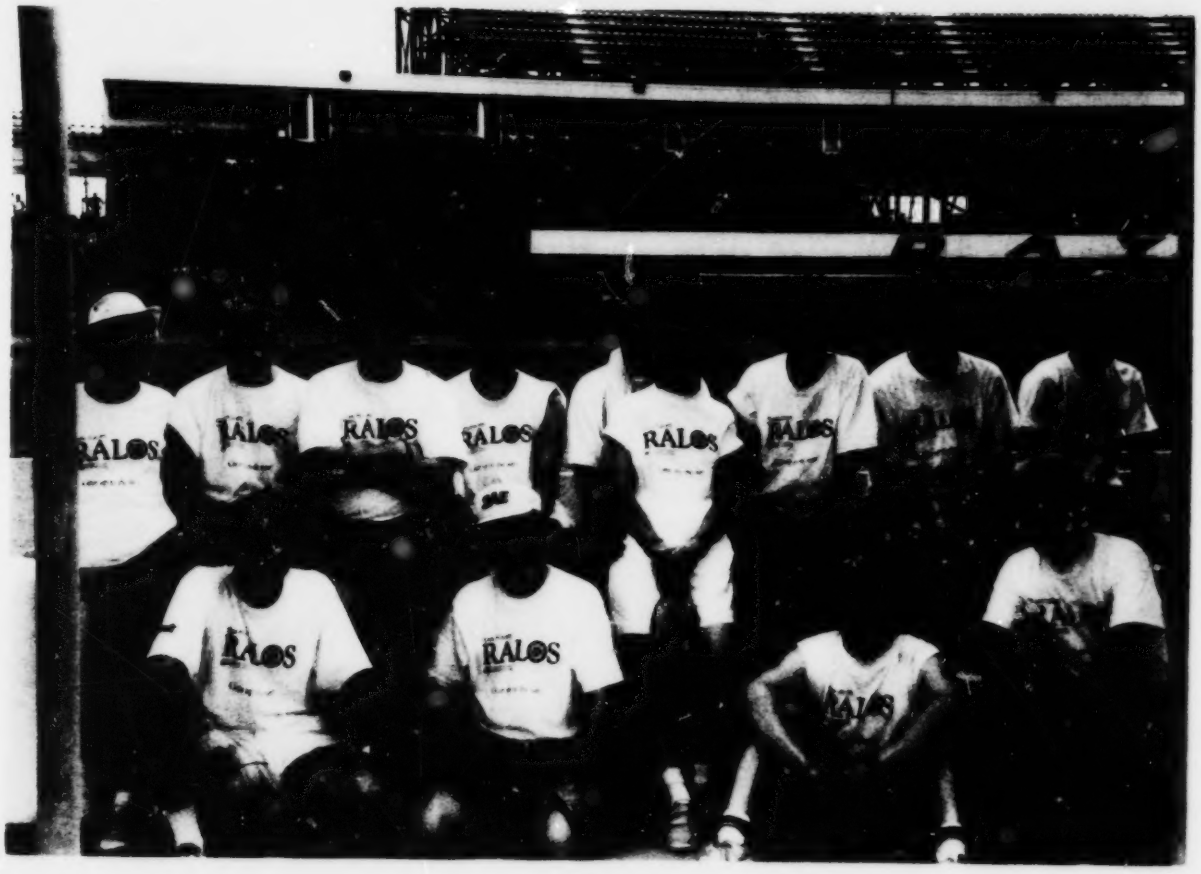
Ralos team members at the University of Ottawa.

Front row,
left to right: Wendy Pell, Stephanie Lines, Lisa Nash

Second row,
left to right: Etienne Bernard, Jules Leduc, Patrice Quevillon, Raed Abdullah, Darcy Ladd, Stephane Quevillon, Julio Oliveira, Paul Therrien

Third row,
left to right: Dr. Atef Fahim, Bashar Abdullah, Dr. Bill Adams, Tom Adams, Yves Dontigny, Andrew Hicks, Pierre Dugas

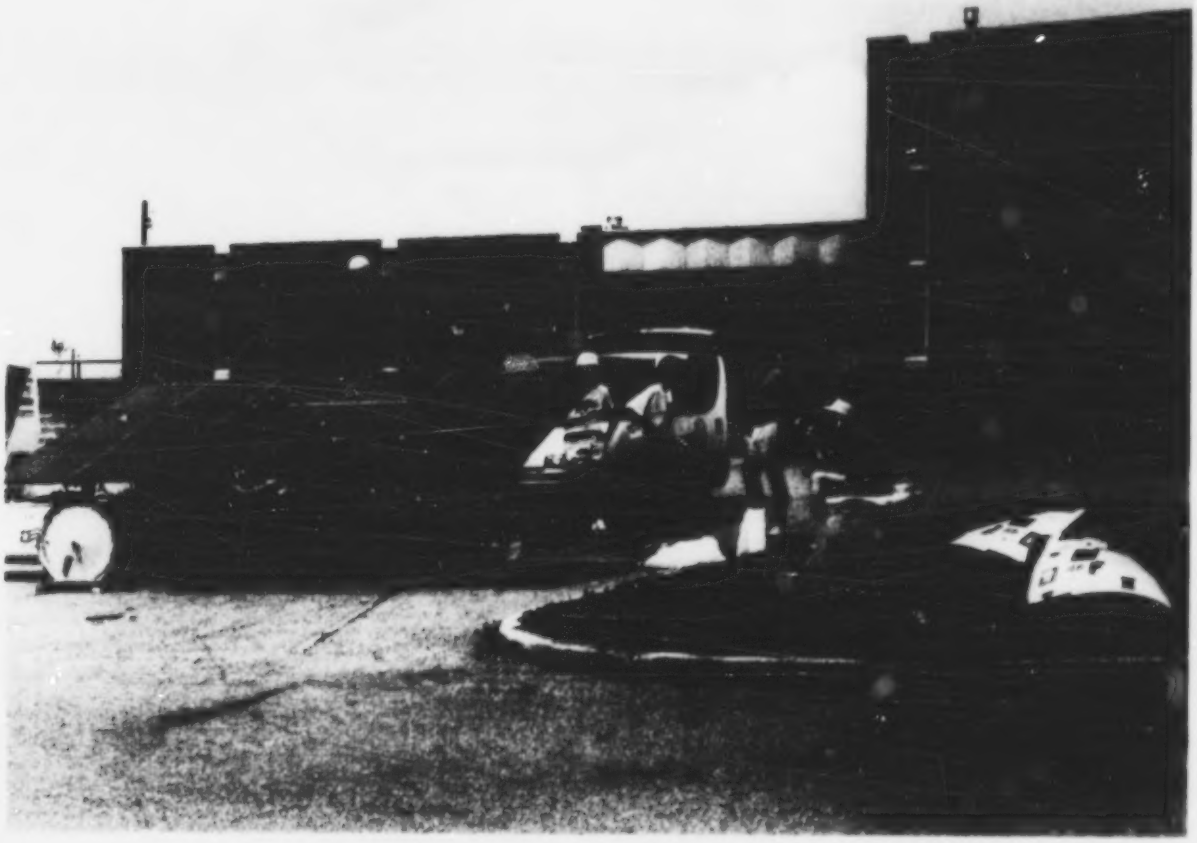
Missing: Sean Rafferty, Andrew Green



Ralos team members at the Daytona Speedway in Orlando, Florida.

Front row,
left to right: Jules Leduc, Bill Adams, Darcy Ladd, Atef Fahim

Second row,
left to right: Stephanie Lines, Andrew Hicks, Etienne Bernard, Tom Adams, Julio Oliveira, Claudia Oliveira, Wendy Pell, Pierre Dugas, Andrew Green



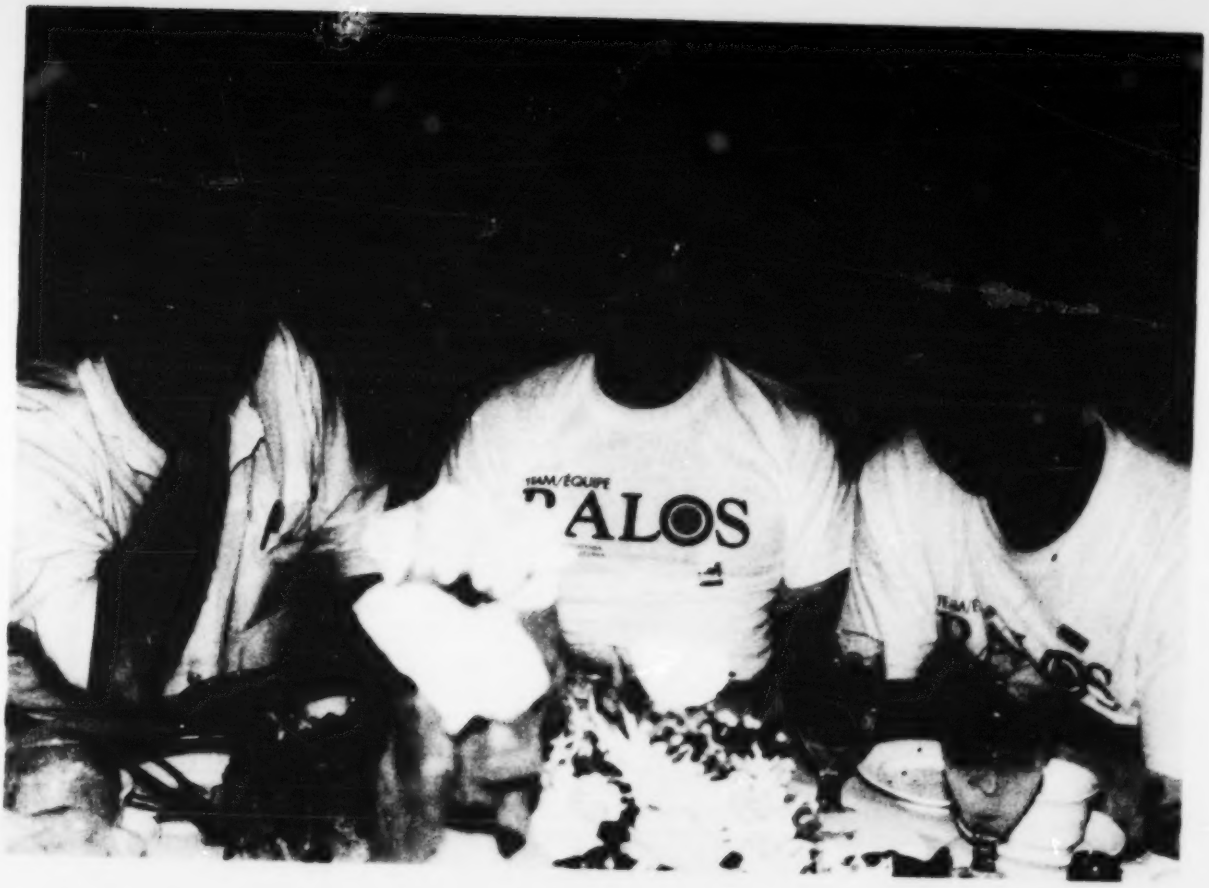
Battery charging during GM Sunrayce.

Team member Paul Therrien works on electrical components.

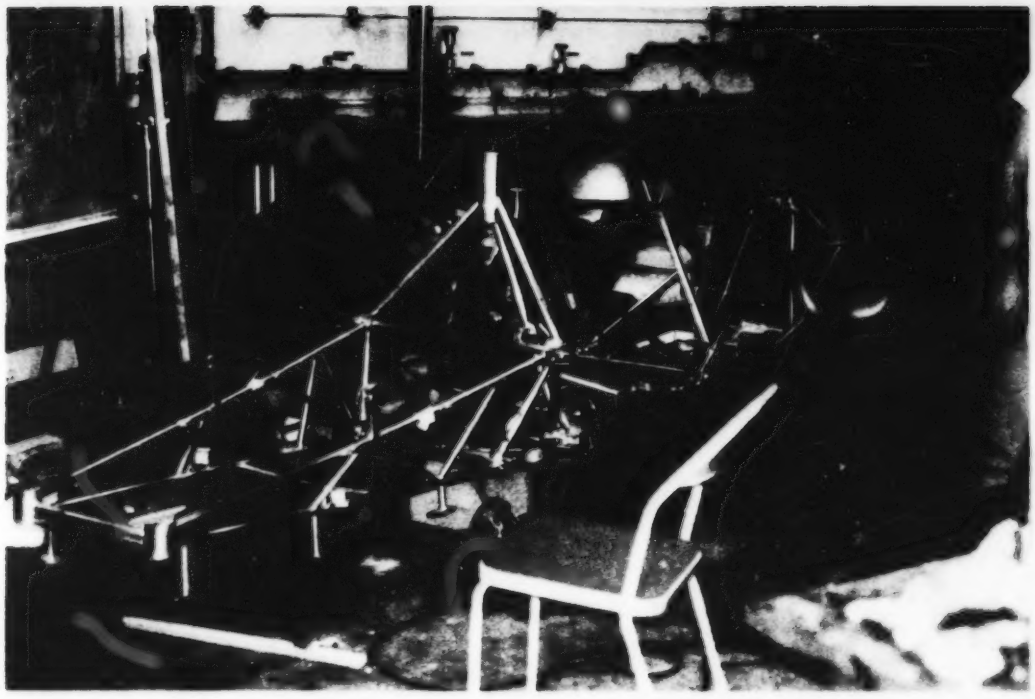
GM Sunrayce is kicked off at Epcot Centre in Florida.

Team members change wheel during qualification trials.

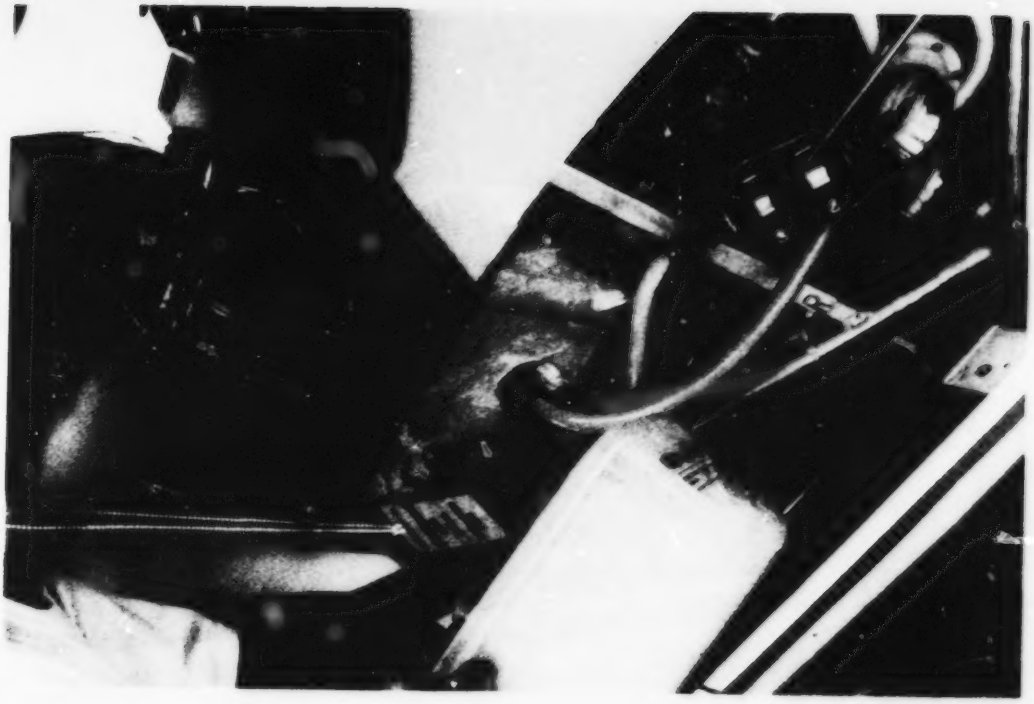
Standing: Atef Fahim
Yellow cap: Yves Dontigny
Red cap: Stephane Quevillon
No cap: Jules Leduc
White cap: GM observer



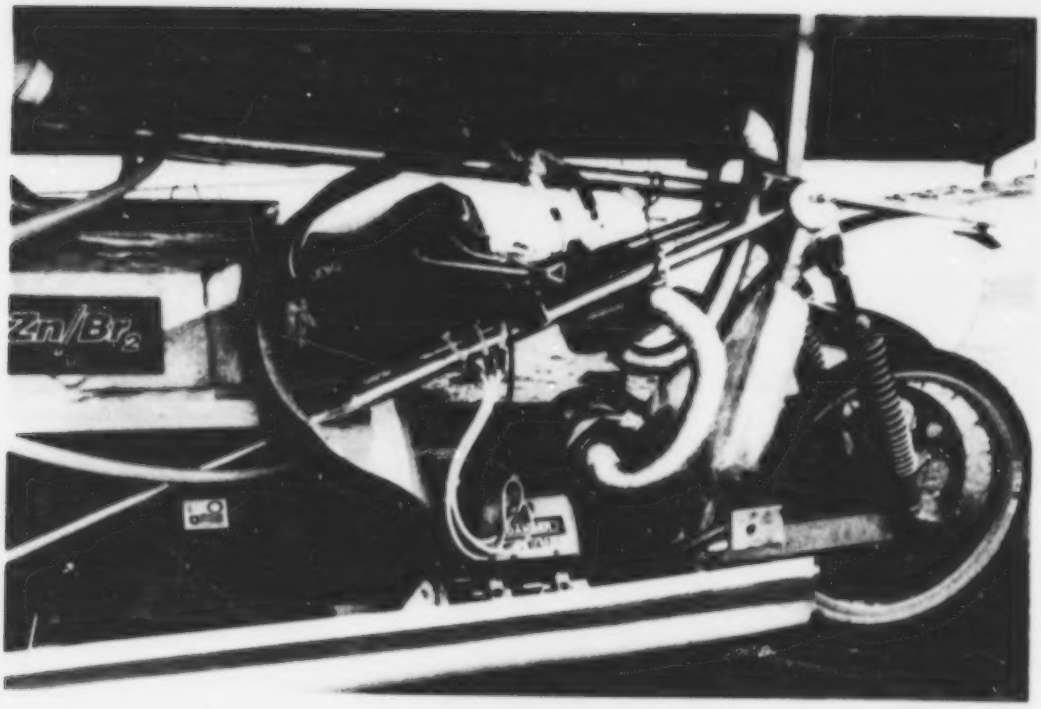
From left to right, Jimmy Royer, Etienne Bernard and Bill Adams at the GM Awards Dinner in Warren, Michigan.



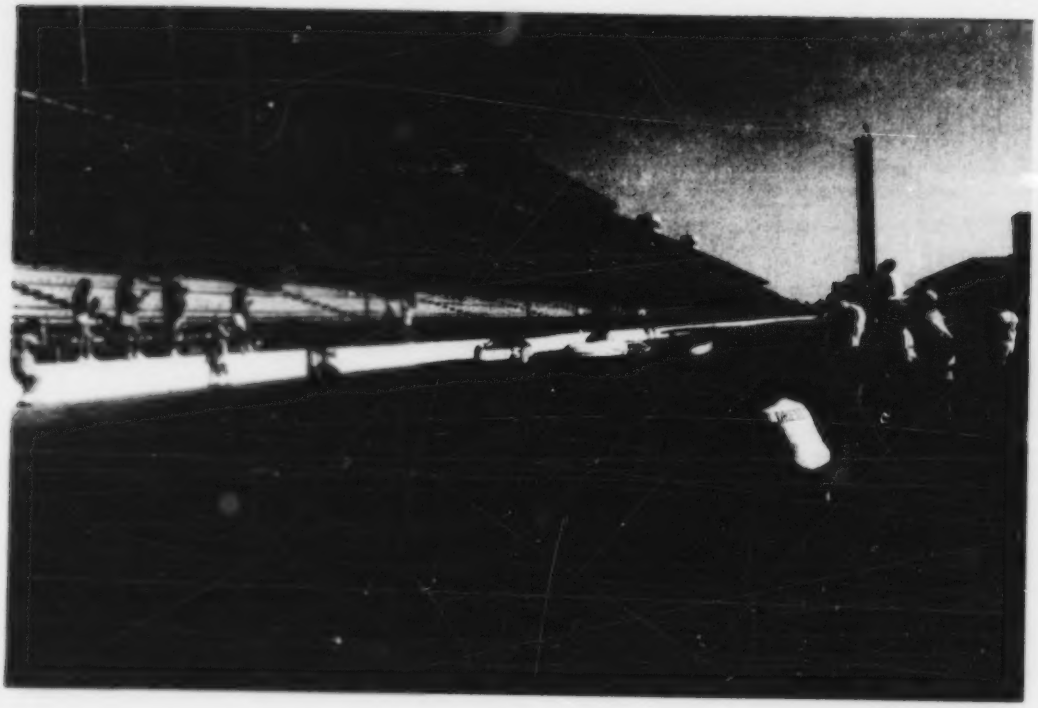
Welding of the aluminum frame.



Team member Stephanie Lines changes ice for heat exchanger.



UNIQ brushless DC high-efficiency motor and zinc/bromine flow battery.



Solar cars at Indianapolis Speedway.

Left to right, team members Stephane Quevillon and Darcy Ladd.